HEATED STAGE FOR A SCANNING PROBE MICROSCOPE

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of U.S. patent application Ser. No. 08/551,836, now U.S. Pat. No. 5,654,546, entitled "A Variable Temperature Scanning Probe Microscope Based On A Peltier Device" filed 7 Nov., 1995 in the name of inventor Stuart M. Lindsay.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to scanning probe microscopy. More particularly, the present invention relates to temperature control of samples under investigation in a scanning probe microscope.

2. The Prior Art

It is often desirable to control the temperature of a sample that is being studied in a scanning probe microscope (SPM) such as the scanning tunneling microscope (STM) or atomic force microscope (AFM). This is because many aspects of surface structure and chemistry are sensitive to temperature, so variable temperature operation adds greatly to the utility of the scanning probe microscope.

Scanning probe microscopes have been constructed which operate in a cryogenic fluid or inside a high vacuum chamber. In each case it is relatively straightforward to control the temperature of the sample (and/or the microscope as well). However, in the case of microscopes designed to operate in ambient air (or some gas at or near ambient pressure) it is more difficult to design a heated sample stage. The reason is that convection caused by hot gasses and temperature gradients across the microscope (the body of which is assumed to be at ambient temperature) causes mechanical instabilities which degrade the resolution of the microscope.

One solution to this problem is to make the heater very small, comparable in size to the probe of the microscope. The heated region itself can then be raised to a high temperature with a very small heat input, with the result that the rest of the sample stage and microscope is not disturbed. Such an arrangement has been built by M. DiBattista et al., and is described in "A Microfabricated Hot Stage for Scanning Probe Microscopes" (1996), using integrated-circuit manufacturing technology. This approach is illustrated in the diagram of FIG. **1**. In FIG. **1** the sample stage **10** is a silicon wafer of high resistivity, onto which is patterned a pair of electrical contacts **12***a* and **12***b*. A small region **14** located between contacts **12***a*, **12***b* is boron-doped so as to make it electrically conductive. Electrical current passed from contact **12***a* to **12***b* (or vice versa) will cause resistive heating in region **14** depending upon the level of boron doping in region **14** and the magnitude of the electrical current applied. Using this technique, the heated region can be made as small as 100 microns or so. While excellent results have been obtained with this system, only the heater itself (or thin films applied to the heater) have been studied so far. The system is too small for routine mounting of larger easily-handled samples. Furthermore, expensive microfabrication procedures are required for fabrication of this heating system.

Another approach, described by W. J. Kulnis, Jr. et al. in "A Thermal Stage for Nanoscale Structure Studies With the Scanning Force Microscope", Mat. Res. Soc. Symp. Proc. Vol. 332, pp. 105–108 (1994), uses a small Peltier thermoelectric device to heat the sample. Peltier thermoelectric devices use electric currents to carry heat from one side of the device to another, and usually find application as small coolers. However, because heat is actively transported across the device, the device itself serves as an excellent 'insulator'. The arrangement of the apparatus of W. K. Kulnis, Jr. et al. is shown in FIG. **2**. In FIG. **2**, a Peltier device **16** is glued onto an X-Y scanner **18** of a scanning probe microscope. A sample to be studied **20** is glued onto the hot side **22** of Peltier device **16**, so that the whole assembly of Peltier device **16** and sample **20** is scanned under probe tip **24** of the scanning probe microscope. This arrangement is simple, however the heat applied to the sample **20** is removed from the cold side **26** of the Peltier device **16** causing thermal gradients at the scanner **18**. The effect is small because much of the current applied to a Peltier device is consumed in Joule heating. However, a second limitation lies with the materials used to fabricate the Peltier device itself: the manufacturers of such devices recommend that they be run at temperatures below 60° C. to avoid damage to internal solder contacts and semiconductor elements, thus the available heating range is necessarily limited by this constraint to about 60° C. or less.

Yet another arrangement has been constructed by I. Musevic et al., in "Temperature controlled microstage for an atomic force microscope", Rev. Sci. Instrum. 67 (7), pp. 2554–2556 (July, 1996). The Musevic et al. arrangement is shown at FIG. **3**. A heater assembly **28**, consisting of a thin film **30** of indium-tin-oxide ("ITO") is coated onto the underside **32** of a glass slide **34**, the underside **40** of which also serves as a support for a sample to be studied by a scanning probe microscope. Heat is developed in the heater assembly **28** by applying an electric current to a multicore, flexible copper wire (not shown) soldered to the ITO surface at diagonally facing corners of the ITO layer **30**. The heater assembly **28** is mounted onto drops **36** of an epoxy adhesive which act as thermal insulating stand-off supports for the heater assembly **28** and hold it onto an X-Y scanner **38** of a scanning probe microscope. This arrangement is capable of heating the sample to higher temperatures than the Peltier-based heater of FIG. **2**, but the entire thermal gradient must be sustained across the epoxy drops **36** and the air space between the ITO layer **30** and the scanner **38**. The thermal gradient across these drops **36** results in excessive thermal drift for some applications. In addition, the inherently small size of drops **36** (typically about 2 mm in diameter) provides only very limited thermal isolation of the sample stage **40** from the rest of the microscope and thus the rest of the microscope is substantially radiatively heated when the stage is hot.

SUMMARY OF THE INVENTION

A heater for use in heating a sample stage of a microscope such as a scanning probe microscope is bonded to a sample stage which sits on a tube of a ceramic thermal insulator which is, in turn, mounted within or part of a tube of the same material. This re-entrant design provides an increased thermal path over straight line distances between the heater and the support structure for the sample stage and thus provides excellent thermal insulation, while also maximizing the thermal stability of the system.

OBJECTS AND ADVANTAGES OF THE INVENTION

Accordingly, it is an object and advantage of the present invention to provide a heated stage for a scanning probe microscope.